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# New Zealand Agricultural and Resource Economics Society (Inc.)

## **Integrated assessment of the environmental, economic and social impacts of land use change using a GIS format – the CLUES model**

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**Paper presented at the 2009 NZARES Conference  
Tahuna Conference Centre – Nelson, New Zealand. August 27-28, 2009.**

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# Integrated assessment of the environmental, economic and social impacts of land use change using a GIS format – the CLUES model

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## Abstract

The CLUES model is an integrated catchment based model that designed to assist policy makers in understanding the implications of land use scenarios for water quality and a range of other indicators. CLUES integrates a number of existing models from several research providers, including SPARROW (catchment hydrology), OVERSEER and SPASMO (nutrient losses), ENSUS (nitrate leaching risk), and a socioeconomic model. These are combined in a GIS framework which allows scenarios of land use to be assessed in a spatial manner. Regional council staff have been trained in its use, and the model is under ongoing development in response to feedback from users. This paper discusses the overall framework of the CLUES model, and discusses in greater depth the socio-economic components and their integration with the biophysical models.

**Keywords:** sustainability indicators, catchment models, water quality, economic impacts, land use change.

## Introduction

The water quality implications of land use change and intensification are a major issue for land managers in New Zealand. The *State of the Environment 2007 Report* (MfE, 2008) shows a small increasing trend in nutrient loading in monitored rivers (~0.5–1 percent), and this trend is significantly worse for the most nutrient-enriched rivers. It notes that:

*“there is strong evidence at both the regional level (Environment Waikato, 2004; Hamill & McBride, 2003) and nationally that the levels of nutrients in rivers increase in proportion to the levels of agricultural activity in river catchments. The amount of nutrients going into the land from fertiliser application and livestock continues to increase in New Zealand as farming becomes more intensive.”*

In some areas, even if nutrient inputs stabilise or decrease, the water quality will continue to decline for some time due to long lag times for nitrates to move through groundwater systems.

While field-scale nutrient budgeting models are available to assist land managers in planning to manage these water quality impacts, and detailed dynamic models have been applied to specific catchments, there have previously been few planning-level tools available in New Zealand to predict the effects of land-use change at catchment, regional or national scales. The CLUES (Catchment Land Use for Environmental Sustainability) project was initiated in 2003 by the Ministry of Agriculture and Forestry (MAF) and the Ministry for the Environment (MfE). The objective was to tie together a number of models into one GIS platform to facilitate assessments of the progressive effects of land use change on water quality in lakes, rivers, and coastal regions.

This paper outlines the CLUES model and goes on to describe in more detail the socio-economic modeling component.

## **The CLUES model**

CLUES contains databases, a user interface, and graphical display, and models housed within ArcGIS (Figure 1). A national spatial database of all the spatial layers required for the model is provided, although the user may also import land-use layers. A graphical user interface is provided for the model, so that the user may easily identify the study area of interest, set up land-use scenarios interactively, and view results. Users with a knowledge of GIS may also make use of broader ArcGIS functionality to further manipulate the land-use and output displays.

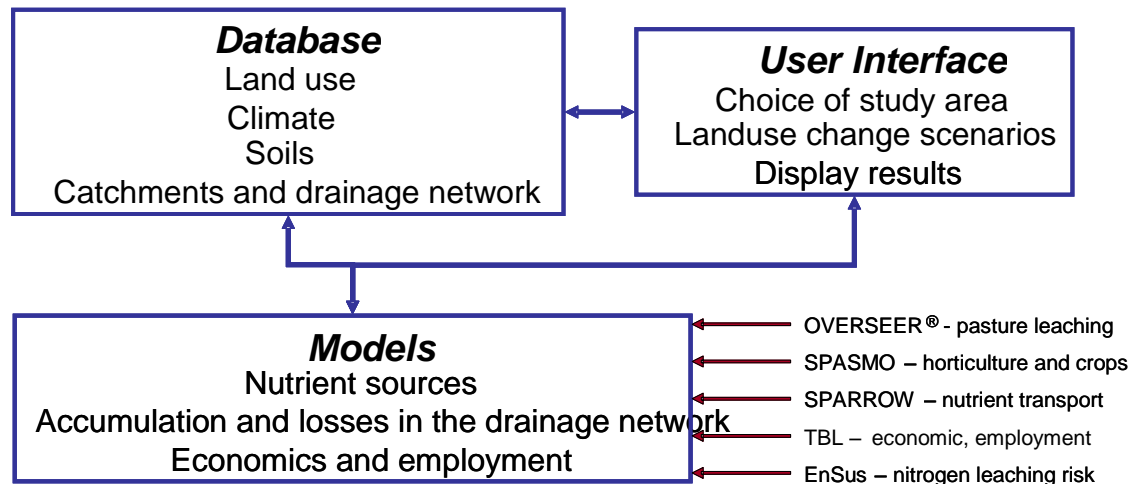
The spatial framework of the model is built around the stream network and associated subcatchments of the REC national stream network. The network has approximately 500,000 stream reaches with subcatchments of 0.5km<sup>2</sup> area on average. The mixture of land-use within a subcatchment is specified, but not the locations of the land-uses within the subcatchment. This level of spatial resolution is suited to studies from the catchment scale to national scale, but not for paddock-scale management.

CLUES draws on a number of models from a number of research providers to provide these predictions:

- SPASMO (Soil Plant Atmosphere System Model, HortResearch) [Rosen 2004]. This is a daily model of water and nutrient flux, and is used for prediction of nitrogen leaching from horticultural land-uses. Rather than run the daily SPASMO model within CLUES, a meta-model of mean annual leaching as a function of land-use, region, and rainfall was derived from a number of long-

term SPASMO runs. This meta-model is implemented as a look-up table within CLUES.

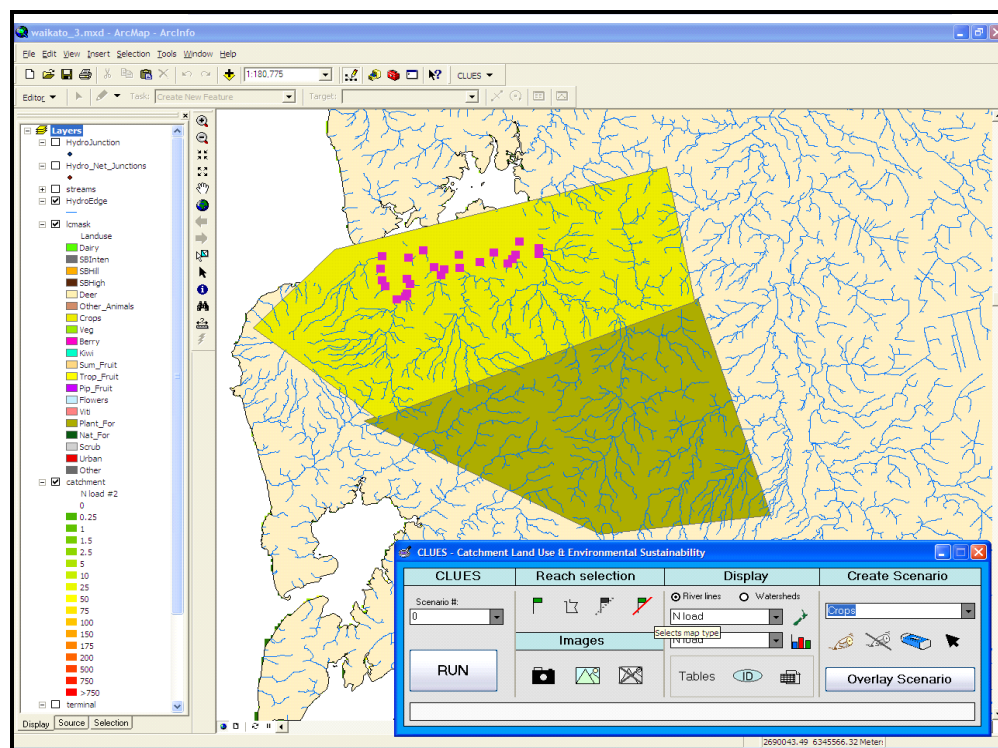
- OVERSEER Nutrient Budget Model (AgResearch) – is a farm-scale nutrient loss model for various land uses (dairy, sheep/beef lowland, sheep/beef hill country, sheep/beef high country, and deer). It provides annual average estimates of nitrogen losses from these land uses, given information on rainfall, region, soil order, topography, and fertiliser applications. A simplified version of Overseer is used in CLUES, driven by representative regional inputs (such as herd composition for a particular land-use) where necessary.
- TBL (Triple Bottom Line, Harris Consulting) [Woods et al. 2006] - estimates economic output from different land use types (pasture, horticulture, forestry and cropping), in terms of Cash Farm Surplus (CFS), Total GDP and Total Employment. The calculations are based on the MAF Farm Monitoring models.
- Ensus (Landcare Research) - provides maps of nitrate leaching potential. This is used as an adjunct to interpretation of CLUES results. It is based on studies of nitrogen losses at national and regional scales [Parfitt et al. 2006].
- SPARROW (USGS, NIWA) [Smith et al. 1997, Elliott et al. 2005] – is used for the E. coli model, and to assess diffuse sources of nutrients not provided by the OVERSEER or SPASMO models. SPARROW also provides the spatial framework for accumulation and routing of loads, and it includes provisions for loss processes in streams and lakes or reservoirs. The extra source terms and decay parameters are determined by calibration to national and regional water quality data.



**Figure 1.** Schematic representation of the CLUES model.

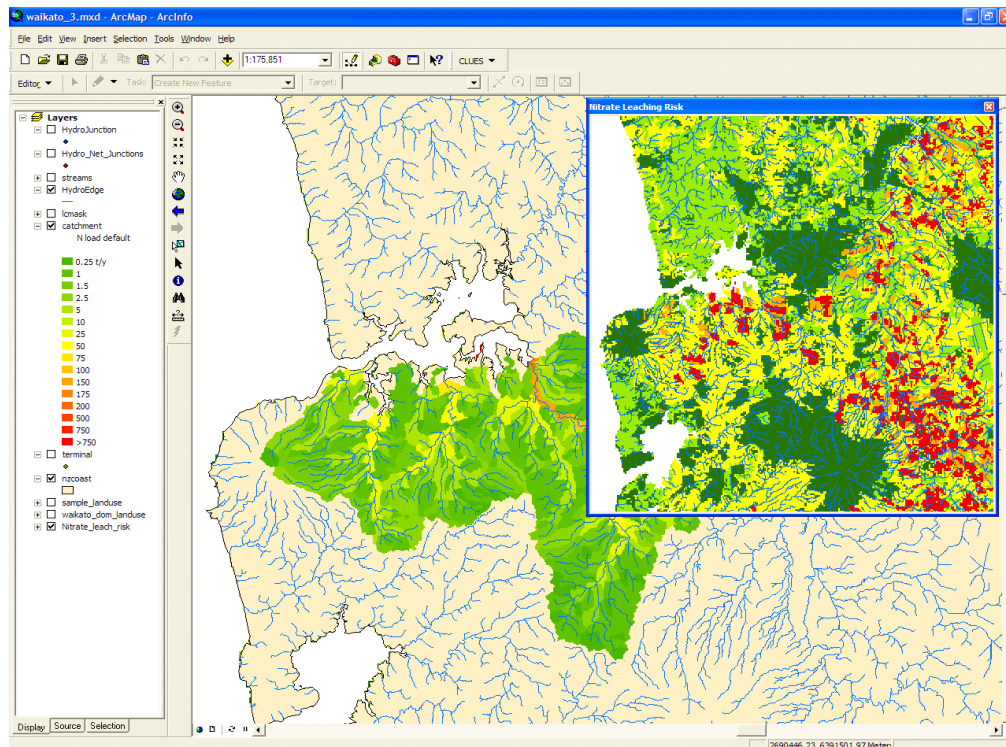
The user interface is written within ESRI ArcGIS, but a custom control panel is used rather than the conventional ArcGIS toolbars, to make the system more appealing to users with little GIS background (Figure 2). The interface manages the reach selection, run control and scenario management, output display, land-use modification, and data or map export. Users familiar with GIS can also use the complete set of ArcGIS features to manipulate the land-use and mapping. The system allows the user to draw polygons of new land-uses, which enables a quick examination of the effect of land-use change. For more advanced uses, land-use can be modified externally and then imported (for example, to specify a fractional conversion of land-use or to make the changes dependent upon other factors such as slope).

Results can be displayed as maps in a variety of forms (Figure 3), or as tabular output and summaries. A tutorial manual is now available from NIWA [Semadeni-Davies et al. 2007]. Values of interest, such as the nutrient load or farm profit can be displayed either as local values associated with a subcatchment or as values accumulated in the upstream catchment.



**Figure 2.** Tool-panel and interactive modification of land-uses [Semadeni-Davis et al, 2008]





**Figure 3.** Example map of model predictions. The subcatchments are coloured according to the nutrient load in the associated stream reaches. An accompanying more detailed map of nitrogen leaching risk for the current land-use is also shown. [Semadeni-Davis et al, 2008]

Land uses addressed include

- Horticulture: avocado, berry, citrus, flowers, grapes (2 regional models), kiwifruit, pipfruit (2 regional models), squash, summerfruit, vegetable(generic), onions (2 models) and potatoes (2 models)
- Arable and maize
- Pastoral: dairy (6 regional models), deer (2 regional models), sheep and beef (6 intensive models, 6 hill country models, 1 high country model)

At present, the system provides predictions of the following biophysical measures:

- Total phosphorus (TP), total nitrogen (TN) and E. coli loads and yields for each stream reach, and loads generated from each subcatchment. A sediment component is in the process of being added.
- Leaching risk for nitrogen (on a relative scale from very low to very high) for the current land-use, displayed as a grid with 100 m resolution (a departure from the spatial framework described above).

The range of socio-economic indicators in CLUES are discussed below.

## Socio-economic indicators in CLUES

The socioeconomic or Triple Bottom Line (TBL as they are called within the project) component of CLUES aims to include indicators for impacts of land use change that are in the economic and social sphere. Indicators are a way of representing a real world phenomenon in a manner that is tractable, understandable and in a CLUES context able to be manipulated and aggregated. It is necessary to understand of indicators that:

- They only represent part of any phenomenon – it is thus necessary to have a number of indicators that is able to describe any phenomenon that humans value or interact with.
- The usefulness of an indicator will vary according to its audience. Different stakeholders will value different aspects of any phenomenon, and as such they will require different indicators. Thus a blind man may define a rose by its touch and scent, where a sighted person will use colour and shape, and a botanist will use other indicators to differentiate.
- Different contexts require different indicators or representations of the same indicator. An indicator at the farm level may not be useful at the international level – for example profit may be important at the farm level but less useful at an international level.

The CLUES programme uses the mosaic approach [Giampetro and Mayumi, 2004] to the inclusion of indicators - this tries to describe a phenomenon through as many different indicators as can be found. The mosaic approach allows users and decision makers to choose from a range of indicators that best fits the scale being considered, and best describes the characteristics they value.

The indicators in CLUES are intended to be generated in real time as the model runs, so that users can interactively be presented with the “full picture” on the implications of a land use change. Three constraints were applied for inclusion of TBL indicators in CLUES - mathematical tractability, availability of data, and its ease of understanding.

**Mathematical tractability** - indicators in CLUES must be able to be manipulated mathematically while retaining their coherence and usefulness. CLUES assesses outcomes at the level of individual parcels at the subcatchment level (which may or may not correspond to properties), and aggregates these up to a higher level. Any indicators which cannot be reliably manipulated in this fashion are not suitable for inclusion in CLUES. This effectively excludes qualitative indicators from inclusion<sup>1</sup>.

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<sup>1</sup> Although there is some potential to use Multi Criteria Analysis techniques within the CLUES framework which will be explored as the programme progresses.



**Availability of data** - Including indicators in the CLUES framework is relatively data hungry

- The framework is national yet requires data at least at the regional and often subregional level
- There are a number of different land use types,
- The data must be kept up to date in order to retain its relevance.

Indicators for which reasonably reliable and readily updateable data was not available have not been included in the model.

### **Understandability -**

A third criterion has been applied to the indicators – that they must be reasonably intuitive to aid understanding by stakeholders. Thus complex indicators which require extensive black box manipulation within the model have been eschewed in favour of simpler indicators that can be readily understood.

## **Economic Indicators**

The economic indicators are based on existing survey data – primarily using MAF Farm Monitoring data<sup>2</sup> (which in turn draws on DairyNZ and Meat and WoolNZ data), and MAF Forestry Statistics data. Updates are obtained directly from MAF as a database query, which can then be fed automatically in to the CLUES system to create the new a rolling 3 year average. The economic indicators used are discussed below.

### **Cash Farm Surplus**

Cash Farm surplus (CFS) is the remainder after farm working expenses have been deducted from Output, but before interest, leases, wages of management, and capital expenditure. CFS is the primary on farm indicator, and is used as a proxy indicator for on farm welfare – but *should not be taken as a direct measure of on farm welfare*. This measure reports the implications for a farm operation of a land use change. It is analogous to, but not equal to, a gross margin, EBITDA<sup>3</sup>, and direct GDP (which would require wages to be added back in).

CFS is calculated by subtracting Farm Working Expenses (FWE) from the Output. Output is calculated from average output - for pastoral land uses this is multiplied by the stocking rate (cows or su/ha), and for arable, horticultural and other land uses the average per ha output is used.

FWE are fixed for arable and horticultural land uses, but for pastoral land uses have been divided into two parts:

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<sup>2</sup> <http://www.maf.govt.nz/mafnet/rural-nz/statistics-and-forecasts/farm-monitoring/>

<sup>3</sup> Earnings before Interest, Tax, Depreciation and Amortisation.

- Fixed FWE based on those expenses which are not expected to change at the margin when stocking rate changes.
- Variable FWE are those expenses which are expected to change as stocking rate and production changes. Variable FWE are determined on a cost/su basis, using the base FWE from the MAF model, and by the addition or subtraction of feed and nitrogen.

For forestry gross harvest revenues are determined by forest outturn and prices received. An estimate of forest outturn by wood supply region (Table 1) has been developed by combining the silvicultural specific yield tables given in MAF's National Exotic Forest Description (NEFD)<sup>4</sup> Yield Tables (1995) on an area weighted basis for individual regions and according to the log grade splits for the region. These estimates of log turnout are multiplied for the national log price series to generate a total output.

Harvest, transport and silvicultural expenses are subtracted from the output. Harvesting costs have been assigned on a regional basis for both ground based and hauler harvest methods based on slope class. Transport costs are difficult to estimate because of regional variations in log transport. The derivation of transport costs utilises a fixed cost /m<sup>3</sup> and a variable /m<sup>3</sup>/km cost, with transport distances derived within the CLUES model. Silviculture costs recognise pruned and unpruned regimes, and an annual overhead charge is made in addition to these costs.

CFS has been used as a primary economic indicator because it is simple to calculate, readily accessible to farmers and other land users, and readily updateable using existing datasets. However because it does not include capital costs, it is to some extent artificial since some land uses require considerably greater capital inputs to achieve their CFSs. There is a particular problem with forestry, where the only way to adequately create a CFS is to average the harvest gross margin over the rotation length. This effectively treats the forested area as if it were in a permanent steady state rotation, which is unlikely to be the case where land use change occurs. The inclusion of capital charges in forestry has a very significant impact on its profitability.

### **Welfare change**

In order to address shortcomings of the CFS as a measure of welfare, a set of measures was developed to provide an estimate of welfare differences as a result of land use change. This involved estimation of changes in capital cost and wages of management (WOM) differences between land uses. A matrix of land use changes with associated capital cost/WOM implications was developed. However this has proven time consuming computationally, and difficult to update, and is not fully implemented at present. As a result only CFS is currently available in the CLUES model currently, but this may change if demanded by users.

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<sup>4</sup> MAF's (2006) National Exotic Forest Description (NEFD)

## Regional Economics

The model includes a set of regional multipliers for major land use categories (dairy, sheep, beef and deer; arable; and horticulture) based on models prepared for MAF in 2000 by Butcher Partners. These are being slowly updated with more comprehensive regional models developed in the P21 Values programme run by AgResearch [Montes de Oca Munguía et al, 2008]. To date more explicit multipliers have been included for Waikato and Horizons MW (in process).

The regional multipliers use the estimates of output within the CLUES model to provide run time estimates of:

- Direct and indirect GDP
- Direct and indirect employment

## Accuracy

The CFS estimates have been compared with data provided by DairyNZ and Meat and Wool NZ for the purposes of developing a regional I/O model in the Waikato. The results are shown in Tables 1 and 2 below, and suggest that the output and CFS estimates are reasonably accurate in the sheep and beef context, particularly for more intensive operations, but exhibit some difficulties when assessing dairy operations.

Further examination of the dairy data showed that the Farm Working Expenses were being estimated reasonably accurately, but that the revenue was not. Discussions with DairyNZ staff suggest that this is because farm operations with higher per ha milk solids production tend to exhibit both higher per cow performance and higher stocking rates – suggesting that either management improves, or utilization of feed improves (or both) with higher stocking rate. The original data provided by DairyNZ was ranked in quartiles for milk solids, and when the data was re-ranked for stocking rate the size of the error margin between the CLUES and DairyNZ data decreased (Table 3).

**Table 1: Comparison of CLUES estimates for economic indicators (per ha) and Meat and Wool 2004 data for Waikato region**

	<b>Waikato Intensive</b>	<b>NI hill</b>	<b>NI hard hill</b>
	<b>Q1</b>	<b>Q2</b>	<b>Q3</b>
Output CLUES/output actual	-6%	-11%	8%
FEW CLUES/FEW Actual	-13%	-14%	28%
CFS CLUES/CFS actual	2%	-6%	-19%

**Table 2: Comparison of CLUES estimates for economic indicators (per ha) and DairyNZ 2004 data for Waikato region (DairyNZ data ranked for milk solids production)**

	<b>DairyNZ data (ranked for milk solid production)</b>			
	<b>Q1</b>	<b>Q2</b>	<b>Q3</b>	<b>Q4</b>
Output CLUES/output actual	29%	14%	2%	-12%
FEW CLUES/FEW Actual	-4%	-4%	-4%	-5%
CFS CLUES/CFS actual	75%	34%	9%	-18%

**Table 3: Comparison of CLUES estimates for economic indicators (per ha) and DairyNZ data for Waikato region (DairyNZ data ranked for stocking rate)**

	<b>DairyNZ data ranked for Stocking rate</b>			
	<b>Q1</b>	<b>Q2</b>	<b>Q3</b>	<b>Q4</b>
Output CLUES/output actual	1%	-3%	-7%	-6%
FWE CLUES/FWE Actual	8%	5%	-3%	12%
CFS CLUES/CFS actual	-9%	-16%	-13%	-35%

While the data comparisons are small, the tables suggest that the approach used for estimating economic indicators for CLUES are likely to give a reasonable answer where the production characteristics are near the mean for the region. Given the likely size of error margins around estimates of land use and stocking rate, we consider this performance satisfactory, although with further regions becoming available for assessment further consideration may be given to a non linear approach to estimating dairy farm output. Care is needed in this area however as we are not able to use the DairyNZ data to distinguish between management causing higher per su output (not reflected in CLUES), and underlying resource reasons (are reflected in CLUES).

## Other indicators

While the majority TBL component in CLUES has focused on economic indicators, it is the ambition of the programme to develop a range of further indicators to give a suite of socio-economic indicators that decision makers can consider when assessing land use change scenarios. The indicators that have been included in CLUES are shown in Table 4.

**Table 4: Other indicators available in CLUES**

Value	Indicator	Comment
Energy	Total Fossil fuel use (aggregate and per ha)	Based on output multipliers from IO table development by Montes de Oca Munguía et al 2008 (Waikato, HorizonsMW only)
	Total Energy Use (aggregate and per ha)	
	Farm energy output (aggregate and per ha)	Estimated from physical production parameters, updated annually.
	Farm protein output (aggregate and per ha)	
Greenhouse gases	Farm greenhouse gas output (CO2 equivalent) (aggregate and per ha)	Based on output multipliers from IO table development by Montes de Oca Munguía et al 2008 (Waikato, HorizonsMW only)
	Total greenhouse gas output (CO2 equivalent) (aggregate and per ha)	
Labour	Direct Cash Farm Surplus per direct FTE	Calculated internally from other estimates
	Total GDP per FTE	
	FTE/ha	

Further indicators are planned to address infrastructure and quality of life, landscape, biodiversity and environmental efficiency (output per unit of environmental stress).

## Summary

CLUES is a major decision support models for land managers, and has level of sophistication and scale that is not available elsewhere for surface water catchments. The approach taken is not intended to provide the complete and most accurate set of outcomes for assessing land use change, but it is a tool that will allow land managers to assess a range of scenarios with relative ease (relative being in relation to other options). The project team has focused on the ability for land managers to iterate and test ‘what if’ scenarios, and we consider that it is likely to be very useful for use in conjunction with stakeholder consultation, and potentially even involving stakeholders directly in deliberations. It is not however intended to provide a tool that can be used to determine individual land use decisions, and furthermore we consider it likely that in specific locations where high impact policies are proposed, more detailed and site specific investigations are likely to be required

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